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THE OCCURRENCE OF HAIL

EDITOR'S NOTE.—In response to the demand for more specific data on the occurrence of hail in the United States, the Weather Bureau began in the April number of this REVIEW the publication of reports on the occurrence of hailstorms as observed by its regular and cooperative observers, numbering approximately 5,200. Cooperative observers report directly to the Weather Bureau officials in charge of the several section centers and these officials in turn transmit the reports to the Central Office in Washington, D. C. The reports are incorporated in the table which hitherto has borne the title "Severe Local Storms." That table will be found on pages 324–325 of this REVIEW, and it will appear in approximately the same position hereafter.

ON A SIMPLE METHOD OF RECORDING THE TOTAL AND PARTIAL INTENSITIES OF SOLAR RADIATION

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(Washington, June 14, 1924)

Synopsis.—A simple form of recording pyrheliometer is obtained from the combination of a thermopile of the Moll type with a recording voltmeter of the Richard type. The large-surface thermopile is composed of 80 elements made from thin strips of manganin and constantan, which are placed in a circle nearly 2 cm. in diameter. These strips can be exposed to radiation over their whole length.

The thermopile is question affords a high degree of stability (absence of zero errors) and sensitivity, together with great quickness in action, namely, the time elapsing between the admission of radiation and the moment at which the full electro-motive force is reached, is less than two seconds. The radiation from a candle at one meter distance yields about 90 microvolts.

Other details and some historical data are given.

With a recording voltmeter (Richard type) the large-surface thermopile, properly diaphragmed and equatorially mounted (clock driven), gives a new form of thermoelectric pyrheliometer, very rugged, and simple in use even for inexperienced observers. A solar radiation intensity of one gram-calory per minute per square centimeter of surface normal to the incident rays develops a current having an electromotive force of about 16 millivolts; this voltage is very nearly proportional to the intensity of the solar radiation so that the pyrheliometric records can be directly calibrated in gram-calories/cm.^{2}/min.

An illustration of the new pyreheliometer is given, with three sample records from measurements made by the author in the Desert of Sahara. The method of obtaining the partial intensities by the use of colored glasses and liquid light filters is also indicated.

THERMOELECTRIC METHOD OF MEASURING RADIATION.

Independent of the ordinary thermometric method, the endeavors to apply the thermoelectric current to measurements of radiation date back several years. Special attention may be called to the old thermoelectric pyrheliometer constructed by Professor Crova and used at the University of Montpellier, France, in 1890. Among other forms we note especially the instrument of Féry, constructed in the beginning of the twentieth century. The difficulties met with in the application of thermopiles for measuring radiation are principally the following:

(1) *Constancy of the zero.*—The thermopile must be free from zero errors.

(2) *Quickness in action.*—The ordinary thermopile is a rather slow instrument; when exposed to radiation a constant temperature will be obtained only after a considerable time; for instance, even in the best Rubens thermopile more than 15 seconds elapse before the full electromotive force caused by constant radiation is reached.

(3) *High sensitivity.*—The sensitivity is generally not great enough to make possible the use of the ordinary millivoltmeters instead of the delicate mirror-galvanometers with the photographic recording. However, when great sensibility has been obtained, it has been at the expense of speed.

(4) *Rugged form of construction.*—The existing thermopiles were not sufficiently rugged for the comparatively rough handling they would meet with in practice for permanent solar radiation measurements.

Through the independent efforts in recent years of two distinguished physicists, excellent thermopiles have been constructed, which may be considered to have overcome generally the difficulties in the application of the thermoelectric methods to continuous measurements of solar radiation.

In consequence of these developments, on the one hand by Doctor Coblentz, of the United States Bureau of Standards, at Washington, and, on the other by Dr. W. J. Moll, lecturer on physics at the University of Utrecht, new forms of thermoelectric pyrheliometers have recently been constructed. To this group of recent instruments, based on the use of the new American thermopile, belongs the excellent thermoelectric pyrheliometer constructed at Washington by Prof. H. H. Kimball and Mr. H. E. Hobbs. On the other hand, on the basis of Doctor Moll's thermopile, a new form of thermoelectric recording pyrheliometer has recently been constructed in Europe and was used during my recent actinometric campaign in the Sahara Desert. I give below a short description of this recording pyrheliometer, which is free from zero error, quick in action, very rugged in construction, and easily worked.

It seems that in the future only the simple thermoelectric method will be in current use, with the restriction, of course, that for control purposes special standard instruments (as for instance the water-flow pyrheliometer of Doctor Abbot) must always be recommended in view of the necessity of controlling and comparing solar radiation measurements.

THE PRINCIPAL CHARACTERISTICS OF DOCTOR MOLL'S THERMOPILES

The paramount object in the construction of these thermopiles is to minimize the heat capacity of the active junctions and to give a maximum value to the passive ones.

The elements from which these thermopiles are made are extremely thin strips of manganin and constantan, soldered at *a* and *c* to copper bars (fig. 1.) These strips can be exposed to radiation over their entire length. The good heat conduction between the junctions, and the small capacity of the junction *b*, causes practically an instantaneous equilibrium of temperature in any case in less than two seconds.

The combination manganin-constantan, with a thermoelectric power of about 41 microvolts per 1° C., has been chosen chiefly on account of the high elastic quality of the two metals, which are soldered end to end and rolled out to the thinness of about 0.005 mm. Of importance also is the durability of the metals, which neither rust nor corrode and also the fact that both manganin and constantan have a resistance which is independent of changes of temperature.

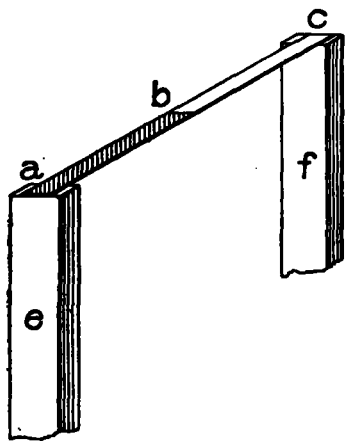

FIG. 1.—Element of Moll thermopile.

Figure 2 is a sketch of the inner part of Moll's thermopile, A is a thick brass plate, in which flattened copper pins B have been clamped. A very thin coating of lacquer forms an insulating layer between these pins and the plate. The thermoelements, soldered on top of the pins, consist of blackened metal strips of only about 5μ (0.005 mm.) in thickness.

All this is sufficient for obtaining both quickness in action and constancy of zero. It is also an important advantage of this construction that the temperature variations do not affect the thermo-electromotive force. An additional advantage is that it is not necessary to screen off the passive junctions; the elements can be exposed to radiation along their full length. Such elements may be combined for building up a linear, just as well as a surface, thermopile.

The large-surface thermopile especially adapted for ordinary measurements of solar radiation intensity, is composed of 80 elements, arranged in three rows and placed in a circle nearly 2 cm. in diameter (fig. 3). The pile, with a resistance of about 45 ohms, is mounted in a solid cylinder which is closed at one end by an ebonite plate with two terminals; and at the other end by a heavy brass lid, into which a protecting window is fixed.

Instead of a rock-salt or ordinary glass window, a plate of fluorite is now used, which transmits all kinds of rays almost without absorption.

The large-surface thermopile of the Moll system gives about 90 microvolts from a candle at one meter distance. The micro-thermopile of 18 elements (suitable for spectral investigations when supplied with a special screen with a slit of variable width) gives about 25 microvolts under the same conditions. Both thermopiles are free from zero errors and combine in an exceptionally rugged form the two properties of great quickness in action with relatively high sensitivity.

THE NEW THERMOELECTRIC PYRHELIOMETER

It follows from the above that the application of the large Moll thermopile for measuring solar radiation gives not only a relatively high thermoelectric current (exceeding sometimes 30 millivolts even when diaphragms are used) but also permits of reaching the final values almost instantly. The solution of the problem of direct and simple recording of the consecutive values of solar radiation intensity, even with the true and quick variations in the corresponding radiation (so frequent especially with cloudy sky) can now be considered as attained, and in a form convenient for general use.

The choice of an appropriate millivoltmeter for direct readings, and especially for automatic records, is an important question chiefly from the practical point of view. The millivoltmeter must not alter the good conditions of sensitivity and quickness of the Moll thermopile; on the other hand, it is highly desirable that the recording millivoltmeter especially should be of simple construction such as the well-known types of Richard's recording instruments.

It is true that the improvement of many details necessitates—chiefly in electrical recording instruments such as millivoltmeters—a certain complication of the construction, as seen in certain new forms of recording voltmeters recently constructed in Europe and in the United States. But, on the other hand, it seems that the simplest form of these instruments is preferable for current use in solar radiation measurements, because they are suitable even for the less experienced observers.

The recording millivoltmeter of Richard, which I have chosen for use with the thermopile of the Moll system, is regularly built for ordinary industrial purposes. It has a resistance of 645 ohms and was used for my radiation measurements with two sensibilities (0–20 and 0–40 millivolts); the clock has two movements; 24 hours and 52 minutes for a complete revolution around the axis. The use of the 24-hour clock allows the observer to keep the instrument in action during the entire day without the necessity of changing the record sheet during this time.

For the maintenance of the thermopile in a position permanently vertical to the solar rays, an equatorially-mounted clock-driven arrangement is used. A special circle serves for the adjustment to the geographical latitude, and a level for the horizontal adjustment. For a quick north-south orientation of the instrument a magnetic needle can also be used.

Figure 4 represents a general view of the thermoelectric recording pyrheliometer [1] and the diaphragmed thermopile equatorially mounted. Instead of a suspension with counterweight, the thermopile may be installed directly on the clock-axis, with provision, however, for a small adjustment in order to follow the variations in the declination of the sun. This must be effected from time to time according to the season.

SOME PYRHELIOMETRIC RECORDS OF THE TOTAL AND PARTIAL INTENSITIES OF SOLAR RADIATION

Without entering into the details which concern more especially physical problems, we note that the voltage of the thermoelectric current generated in the thermopile

[1] This recording pyrheliometer is regularly manufactured, and can be purchased at Etablissements de la Société Jules Richard Paris, 25 Rue Melingue. The actual price is about $250, including the recording millivoltmeter and all the accessories. The recording millivoltmeter costs separately about $100.

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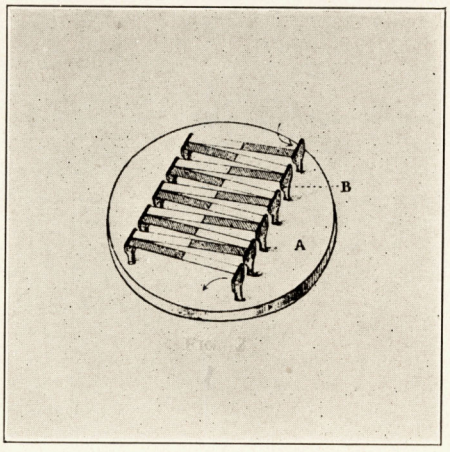

FIG. 2.—Interior view of Moll thermopile

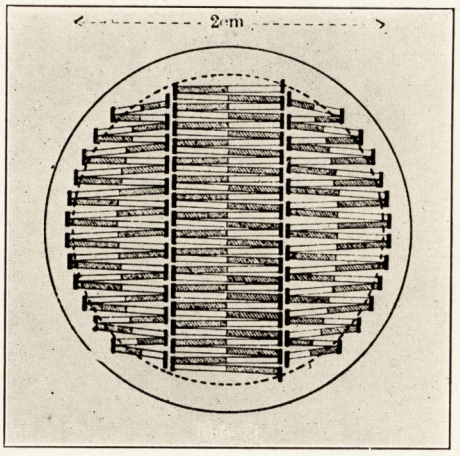

FIG. 3.—Large-surface Moll thermopile

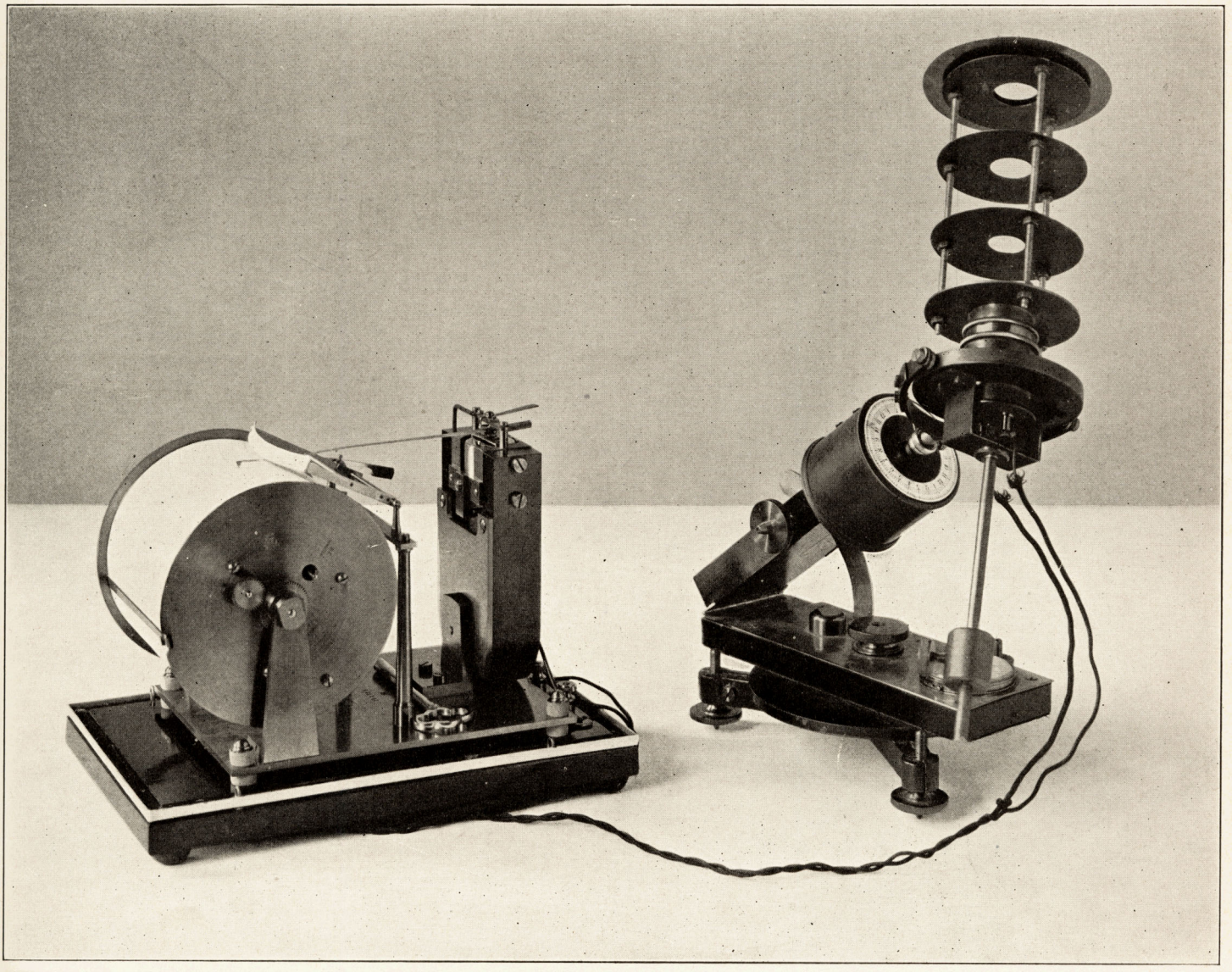

FIG. 4.—General view of recording pyrheliometer

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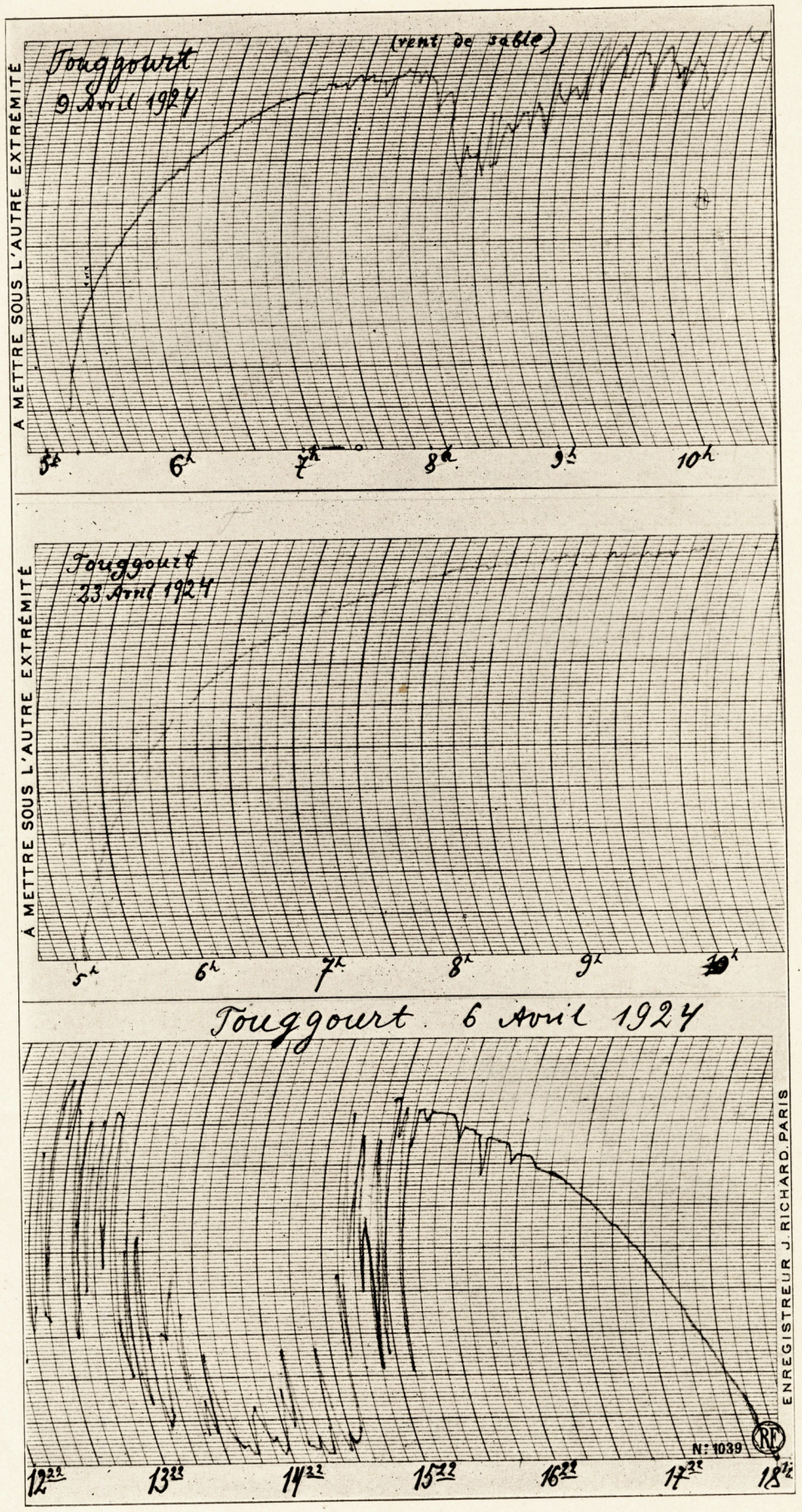

FIG. 5.—Pyrheliometer records obtained in the Desert of Sahara

when exposed to the solar rays can be considered as practically proportional to the radiation intensity. This simple relation enables us to convert directly into gram calories per cm.² per minute the values shown by a millivoltmeter. For this conversion it is necessary previously to obtain the reduction factor for the thermopile used with the corresponding diaphragms; this coefficient can be found either by comparisons with a standard pyrheliometer or by absolute determinations.

We note that with a solar radiation intensity of one gram-calory per minute per square centimeter of surface, the current generated by the large diaphragmed Moll thermopile has a voltage of about 16 millivolts. Besides the thermopile, the millivoltmeters must also be calibrated in order to determine the value of the current indicated by the position of the needle on the diagram. This is done by successively passing currents of 0 to 40 millivolts through the millivoltmeter coils.

Figure 5 gives three examples of pyrheliometric records, obtained by me during the spring of 1924 in North Africa, in the oasis of Touggourt, Desert of Sahara. Owing to the length of the diagrams, only a part of each record is reproduced here.

It is evident from these records that even in the case of frequent passages of clouds the new recording pyrheliometer permits the obtaining of good pyrheliograms, characteristic for the prevalent type of clouds, owing to the quick action of the thermopile. From these records the total amount of radiation, the diurnal march, and average values, can be obtained.

We note finally that not only the total radiation but also the partial intensities of the solar radiation can be easily recorded with the Moll thermopile. For this purpose special light-filters are used which are introduced (by means of a periodical swinging movement) before the aperture of the thermopile.

I have used principally four light-filters, viz:

(1) The so-called marmor glass, opaque for visible rays but with a transmission up to 85 per cent (for thickness of 7.3 mm.) between 0.9 and 2.8μ.

(2) The red glass (Jena F. 4512, thickness 3.95 mm), with a transmission up to 84 per cent between 0.8 and 2.5μ, and opaque below 0.55μ and for the wave-lengths greater than 4.0μ.

(3) The yellow filters prepared by Doctor Moll from 5.16 gr. $K_2Cr_2O_7$ in 100 gr. H_2O. This liquid filter, in a cell 11 mm. thick, transmits up to 98 per cent between 0.7 and 1.2μ, decreasing to 0 per cent for 1.5μ.

(4) The blue filter of 30 gr. $CuSO_4$ in 100 gr. H_2O; it transmits besides short wave-lengths also the radiation of long wave-lengths beginning at 1.8μ.

The use of the light-filters enables us to study, besides the variation of the total intensity, the diurnal changes of the partial intensities of solar radiation. The following extract from the measurements made in the spring of 1924 in the Desert of Sahara, shows some interesting changes in the percentages of the partial intensities in relation to the total intensity of solar radiation.

Oasis of Touggourt, March 28, 1924

(Time: Between 5:52 a. m. and 7:05 a. m.)

Solar zenith distance	Total radiation intensity (gram-cal./cm²/min.)	Percentages		
		Red infra-red	Infr.	Blue
85½°	0.14	67	19	9
83°	0.25	62	18	10
80°	0.28	58	18	12
75°	0.37	54	17	15
71°	0.40	54	15	17

We see here the characteristic decrease from sunrise to noon in the proportion of the red and infra-red rays and at the same time the consecutive increase of the partial intensity of the solar spectrum.

CONCLUSION

From the considerations indicated above, it follows that the new form of recording thermoelectric pyrheliometer possesses in high degree the desired qualifications, namely, quickness of action, great sensitivity, and absence of zero error. On the other hand, the rugged construction of the thermopile, the simplicity of the whole instrument, and especially of the recording voltmeter, make the new pyrheliometer very easy for current use, not only by the meteorological observatories but also by less experienced observers at ordinary meteorological stations. The results, already obtained in the desert regions of North Africa and in the plains of Europe, as well as comparisons just made between this instrument and the Marvin and the Smithsonian pyrheliometers at Washington, D. C., show its convenience, and the practical adaptation of the measurements obtained with the new recording pyrheliometer in the different climates.